

# **Everglades Nutrient Removal Project: Hydrology Hydrodynamics & Operation**

*M. Guardo, PhD, PE*  
*W. Abtew, PhD, PE*  
*J. Obeysekera, PhD, PE*  
*J. Roy*

**SFWMD-HIST-002**

## The Everglades Nutrient Removal Project: Hydrology, Hydrodynamics and Operation

M. Guardo, PhD, PE; W. Abtew, PhD, PE; J. Obeysekera, PhD, PE; and J. Roy<sup>1</sup>

### INTRODUCTION

The Florida Everglades is a unique ecosystem which sustains a variety of flora and fauna that are specific to the region. This ecosystem has been affected by many factors, both natural and anthropogenic. Changes to the natural hydroperiod and increased nutrient enrichment of inflow waters have transformed the floral and faunal communities of the Everglades (Davis, 1991; Koch and Reddy, 1992; Swift and Nicholas, 1987). The increased nutrient loading, primarily phosphorus (P), is largely due to agricultural runoff from the Everglades Agricultural Area (EAA). The 1991 Marjory Stoneman Douglas Everglades Protection Act (Section 373.4592 Florida Statute) requires the South Florida Water Management District (District) to regulate water quality in the Everglades system. The District proposes the development of Storm Water Treatment Areas (STAs) for reducing the P loading to the Everglades. These wetland treatment systems will function as nutrient filters.

The Everglades Nutrient Removal (ENR) project is the first wetland to be constructed and will initially function as a demonstration scale project. This 1500 ha (3700 ac) system, currently one of the largest constructed wetlands in the world, is designed to use different types of vegetated marshes to reduce the total P concentrations and loads in the EAA drainage water. The primary objectives of the ENR project are: 1) to reduce the amount of P in the water flowing into the Loxahatchee National Wildlife Refuge (Water Conservation Area 1, a regulated wetland system which was part of the original Everglades), and 2) to develop wetland treatment design criteria, operation schedules, and maintenance requirements for large scale application of wetland treatment systems (Everglades Systems Research Division, 1993). The experience gained from the ENR project will be used to optimize wetland design and operation of large scale STAs for treating agricultural runoff from over 200,000 ha (500,000 acres) of agricultural drainage basin. The ENR project differs from many other constructed wetlands due to its size, pulsed loading of water, quantity of water to be treated, total P concentration range in which it will operate, and low 0.05 mg l<sup>-1</sup> (50 ppb) total P discharge requirement (Newman, et al, 1993). The purpose of this paper is to describe the hydrology, hydraulics, and operation of the Everglades Nutrient Removal constructed wetland.

### SITE DESCRIPTION

The ENR project site has highly organic soils and flat topography and is located in South Florida, about 32 km (20 miles) west of the city of West Palm Beach (Figure 1). Originally, the area was part of the natural Everglades system that consisted of custard apple and willow-elderberry swamps and sawgrass marshes interspersed with tree islands, wet prairies and sloughs (Davis, 1943). Since drainage and agriculture started in the area over six decades ago, about 1.52 m (5 ft) of the top muck soil has been lost due to soil subsidence, oxidation and shrinkage. At present, the surface 1-2 m (3.28 ft to 6.56 ft) is peat that overlays several meters of carbonate rock (Jammal and Associates, 1991).

The average ground elevation is 3.05 m (10 ft NGVD). A 12 km (7.5 miles) long perimeter levee, excluding the L-7 levee, surrounds the constructed wetland and the enclosed area is divided by internal levees into four treatment cells (Figure 2). The northern two parallel treatment cells (Cell 1 and Cell 2), referred to as Flow-way Cells, are being vegetated mainly through natural regrowth of cattails. The southern two cells (Cell 3 and Cell 4) are referred to as Polishing Cells. Polishing Cell 3 is planted with mixed marsh vegetation composed of Pickerelweed (*Pontederia Cordata*), Arrowhead (*Sagittaria latifolia*), Duck Potato (*Sagittaria lancifolia*), Maidencane (*Panicum hemitomon*), Sawgrass (*Cladium jamaicense*) and Spikerush (*Eleocharis spp.*). Emergent macrophyte growth will be controlled in Polishing Cell 4 and it will be operated as a submerged/algal based

---

<sup>1</sup> Sr Civil Engineer, Sr Civil Engineer, Supervising Professional Civil Engineer, and Civil Engineer respectively. Department of Research, South Florida Water Management District, P.O. Box 24680, West Palm Beach, Florida 33416-4680, USA

vegetation system. A strip of natural regrowth will occur at the outlet of Cell 4. This vegetated area will function as a filter strip to minimize algal outflow.

## HYDROLOGY

Hydrologic characteristics are probably the primary factors that influence and determine the establishment and maintenance of specific types of wetlands and wetland processes. Hydrology creates unique biological, chemical and physical conditions that make wetland ecosystems different from well-drained surface water systems and subsurface aquatic systems (Mitsch and Gosselink, 1986).

To evaluate the nutrient removal performance of the ENR project, nutrient mass and hydrologic budgets are required. A comprehensive water quality and quantity monitoring program was developed to provide parameter data necessary to accurately determine nutrient and hydrologic budgets. Water budgets will be calculated by monitoring rainfall, evapotranspiration, surface inflows, surface outflows, and seepage in and out. The balance of all the above components yields a change in storage, which represents the seasonal pattern of water stages within the wetland.

### Rainfall

South Florida has a humid subtropical weather pattern with warm rainy summers and mild winters. Most of the rain occurs in the summer and fall. The wet season extends from the beginning of June to the end of October. In the Everglades Agricultural Area where the ENR project is found, 66 percent of the annual rainfall occurs during the wet season on the average (Abtew and Khanal, 1993). Wet season rainfall is from convective rainfalls, localized thunderstorms, tropical depressions and hurricanes. The dry season (November through May) rainfall is mainly frontal rainfall. The historical (1929-1991) average annual rainfall for the area is 133.2 cm (52.4 inches) (Abtew and Khanal, 1993).

An accurate water budget of the ENR constructed wetland is required to evaluate and improve the performance of the treatment system. Rainfall, one of the largest components of the water budget, needs to be measured as accurately as possible. Summer rainfall patterns indicate the occurrence of highly localized convective rainfall. Accurate areal rainfall measurement therefore requires a network with a high gage density. The decision was made to install ten continuous recording, tipping-bucket raingages to establish the extent of spatial and temporal variability of rainfall within the ENR. Data from this ten gage network will be used to compute hourly and daily areal rainfall for each cell and the whole site based on the Thiessen method. After one year of data collection, the network will be reevaluated and the number of stations may change according to results of this network analysis. The raingage network is shown in Figure 3.

### Evapotranspiration

Another major component of the ENR hydrologic system is evapotranspiration (ET). Initially, evapotranspiration will be measured with lysimeters (Abtew et. al., 1993). Lysimeters will be installed in each of three vegetation communities; cattails, mixed marsh, and algae covered open water without macrophytes (Figure 3). Actual evapotranspiration measured from the lysimeters, will be used for water budget computation. An illustration of the lysimeter is shown in Figure 4. High resolution weather data will be collected at the site for calibration of the Penman-Monteith equation using concurrent measurements of evapotranspiration with the lysimeters.

### Surface Inflows and Outflows

Water is supplied to the ENR Project via a pump station (G-250). Records for the pump operations will be used to determine discharges into the entrance (Buffer) cell. Water is moved from one cell to another by means of 16.76 m (55 ft) long and 1.83 m (6 ft) diameter circular culverts with risers. A riser consists of an upright half-culvert which contains stop logs acting as a variable height weir. The culverts operate under full flow with downstream control. Water, initially pumped into the Buffer Cell, can be routed into Cell 1 through a series of ten culverts with risers (G-252A-J) or Cell 2 through a series of five culverts with risers (G-255A-E). These 15 risers

are 2.1 m (7.0 ft) in diameter. Outflows from Cell 1 are routed to Cell 3 through a series of ten culverts with risers (G-253A-J) and from Cell 2 to Cell 4 through a series of five culverts with risers (G-254A-E). These 15 risers are 3.7 m (12.0 ft) in diameter. Water exits Cell 3 and Cell 4 into collection canals and is discharged from the project through the outflow pump station (G-251). Records for the pump operations will be used to determine discharges into the Water Conservation Area 1 (WCA-1), supported also by ultrasonic velocity meter (UVM) measurements in the discharge canal. The locations of surface water control structures are shown in Figure 2.

To meet objectives of the ENR project, accurate determinations of hydrologic and nutrient budgets for each treatment cell are required. Preliminary modeling of the ENR Project indicated that 30 percent of the time low flow conditions with culvert velocities less than  $6.1 \text{ cm s}^{-1}$  ( $0.2 \text{ ft s}^{-1}$ ) will exist. Under low flow conditions, the resulting head differential, which is on the order of a hundredth of a foot, does not permit use of stage-discharge equations to accurately calculate flow through the culverts. Therefore, alternative methods for monitoring inflows to and outflows from each treatment cell were evaluated. Previous experience has shown that electromagnetic velocity meters are not reliable under very low flow conditions and are very sensitive to fouling. Any debris or growth contacting the sensor will generate erroneous data. Hence, these meters would require extensive maintenance. Use of mechanical velocity meters to monitor flow requires that they be mounted near the center of the culvert cross section. This design is susceptible to fouling from water column debris and breakage by alligators.

Through peer reviews of the hydrologic monitoring system it was suggested that UVMs could be utilized to determine inflows and outflows to each treatment cell. UVMs operate using a bidirectional transmission of sonic energy between two transducers aligned at some angle to the flow. This technique is based on the principle that a pulse of sound traveling diagonally across a stream will be accelerated by the velocity in the downstream direction and will be decelerated when traveling in the upstream direction. Velocity is computed from the difference between the forward and backward travel time and the angle in degrees between the acoustic path and the flow.

### SEEPAGE

To estimate horizontal seepage into and out of the ENR project, 12 pairs of staff gages and 12 piezometers, located along the perimeter and interior levees, will be used to determine water level gradients. Readings from staff gages and water levels in the piezometers will be collected at the same time in order to accurately determine head gradients. Water levels will be monitored with continuous recording stage gages and periodically read staff gages located throughout the site. Seepage rate coefficients will be determined from tests, and be used to estimate seepage based on head gradient data.

### HYDRODYNAMIC MODELING

Some of the most important parameters affecting nutrient removal in wetland treatment systems are intimately related to water processes. Parameters such as water depths, hydraulic loading rates (HLR), and hydraulic retention times (HRT) can be obtained from hydrodynamic modeling simulations, and play an important role in designing wetland systems for nutrient removal. Hydrodynamic modeling is, in these circumstances, of extreme importance when interacting with water quality modeling. The capability of a model to simulate and predict water quality is dependent on its ability to simulate all the relevant hydrodynamic processes.

Hydrodynamic modeling for shallow water flow in wetlands is, in general, based on the solution of the Saint Venant differential equations, which describe continuity and momentum. In this particular case, the equations are in two horizontal dimensions (e.g. x and y directions) and vertically averaged for incompressible flow (Roig and King, 1992). Their results represent gradually varied, unsteady state flow, which is able to accurately provide flow depths, average flow velocities, hydrographs, flow patterns and HRTs.

Wetland vegetation plays an important role in hydrodynamic modeling. Vegetation influences hydrologic conditions by consolidating the soil against erosion, trapping sediments, building peat deposits, interrupting water flows, and changing flow paths. The influence of vegetation on infiltration and soil water storage is due to plant roots and to the effect of organic matter on and in the soil, and to plant roots. Experiments have shown a positive correlation between the quantity of organic matter present in the soil and its water-holding capacity.

Knowledge of hydraulic resistance in marsh type wetlands is important in any application of the above mentioned equations. It has been hypothesized that longer HRT will result in increased phosphorous uptake. The

HRT for the treatment cells increases as flow resistance increases. Currently, little information is available for resistance values in heavily vegetated wetlands. In most of the previous work, Manning's equation has been used to estimate overland flow resistance as a function of velocity, depth and slope. However, resistance values in marsh type systems are also a function of the distribution of vegetation both laterally and vertically, species composition and seasonal variations. Hydraulic resistance values can be predicted as a function of flow depth and vegetation characteristics.

The SHEET-2D model solves the non-conservative form of the differential equations by means of an implicit finite difference method and a double sweep scheme. This model was used to obtain steady state flow simulations for a range of constant inflows from  $2.12 \text{ m}^3 \text{ s}^{-1}$  (75 cfs) to  $16.98 \text{ m}^3 \text{ s}^{-1}$  (600 cfs). These simulations extended for 30 days with a time step of 30 seconds to assure reasonable accuracy, reaching steady state conditions after 21 days (Guardo and Tomasello, 1993). Flow vectors from these simulation results are depicted in Figure 5.

## OPERATION

A portion of the agricultural drainage pumped out of the EAA is diverted to the ENR project via a 3.4 km (2.1 miles) supply canal that connects to the West Palm Beach canal upstream of the S-5A pump station. The West Palm Beach canal is one of the major channels for agricultural drainage from the EAA and water supply from Lake Okeechobee to the coast and Water Conservation Area 1. The inflow pump station (G-250) moves water from the supply canal into a 55 ha (135 ac) Buffer Cell via six pumps with a total capacity of  $16.98 \text{ m}^3 \text{ s}^{-1}$  (600 cfs). Water is then distributed to Flow-way Cell 1 and/or Flow-way Cell 2 through a series of culverts. Flow rates and water depths are regulated via risers and stop logs. Water is routed from Flow-way Cell 1 to Polishing Cell 3 and from Flow-way Cell 2 to Polishing Cell 4 via culverts with risers and stop logs. Water flows from Cells 3 and 4 into collection canals at the outlet where six pump units discharge the treated water into Water Conservation Area 1. Seepage out of the wetland through the western and northern sections of the perimeter levee is collected in a seepage canal and can be pumped back into the Buffer Cell using three seepage pumps (located at the inflow pump station) with a total capacity of  $5.66 \text{ m}^3 \text{ s}^{-1}$  (200 cfs). At the end of the treatment process, the outflow pump station (G-251) discharges the treated water to Water Conservation Area 1. The outflow pump station has six units with a total capacity of  $12.74 \text{ m}^3 \text{ s}^{-1}$  (450 cfs). If sufficient treatment is not attained with a single pass, water from the end of the system can be recirculated via the seepage canal.

There will be two ENR operation stages, each having distinct water level criteria: the startup phase (Stage I) and the long term phase (Stage II). Stage I will last from one to two years and is divided into two periods: the early startup period and the later startup period. During Stage I, it is necessary to insure good development and growth of the vegetation within the treatment cells. Therefore, mimicking the drainage pumping pattern of the S-5A pump station will be restricted since long periods of flooding with high water depths would damage the developing plants due to the lack of oxygen and light. Following the start-up phase, the long term phase (Stage II) operation will begin. During Stage II, higher water depths will be allowed in the treatment cells. Within the limits of the criteria presented below, as much water as possible should be conveyed to the ENR before the S-5A pumps are turned on during a storm event. According to the preliminary operation scheme of the ENR, the recommended average water depths for maximize plant growth during Stage II should be 61 cm (2.0 ft), 70 cm (2.3 ft), 46 cm (1.5 ft), and 61 cm (2.0 ft) in Flow-way Cell 1, 2, and Polishing Cells 2, 4 respectively (Guardo and Kosier, 1993).

The performance objective of the ENR project is to ensure that its discharge contains a lower phosphorus load than its inflow load from EAA stormwater runoff. Average annual total phosphorus concentration at the outlet should not exceed the corresponding concentration at the inlet during normal pumping from the ENR to the Refuge. To achieve this objective, total phosphorus levels at the inlet of the ENR and at its outlet pump station will be monitored on a weekly basis. The four-week moving average total inflow P concentration will be compared with the four-week moving average total outflow P concentration to account for an average hydraulic retention time (HRT) of approximately 28 days (Guardo and Kosier, 1993).

Controlled experiments to test the effects of water depth, hydraulic loading rates, hydraulic retention times and vegetation type on phosphorus removal will be conducted in two banks of Test Cells. Each bank has 15 cells and each cell has a unit area of 0.20 ha (0.5 ac). One bank of Test Cells is in Flow-way Cell 1 and the other is in Polishing Cell 3 (Figure 3). Results of the experimental work will be used to optimize the detailed design and operation of the ENR and additional STAs that will be constructed along the southern edge of the EAA. The average water depth was considered 60 cm (1.97 ft) and the average HLR  $2.1 \text{ cm d}^{-1}$  ( $0.83 \text{ in d}^{-1}$ ). These values yield the average HRT of 28 days. Two values above and below the average values were considered. They were 90 cm (2.95 ft) and 30 cm (0.98 ft) for the water depths, and  $6.3 \text{ cm d}^{-1}$  ( $2.48 \text{ in d}^{-1}$ ) and  $0.7 \text{ cm d}^{-1}$  ( $0.28 \text{ in d}^{-1}$ )

for the HLRs. Different combinations of water depths and HLRs will be used in the test cells to study several scenarios with different plant species.

### CONCLUSION

The ENR project is a large constructed wetland for the treatment of agricultural drainage. As cattail revegetates naturally and other planted marsh plants fully develop, the former farmland will slowly convert over to a marsh ecosystem after being flooded. This transformation and its implications for nutrient removal will be documented and quantified as a part of a research plan. The ENR project is expected to require at least a year until vegetation is fully established. While the ENR project will become operational after construction is completed, it will not reach full operating performance until the following year. The nutrient removal capability of this ecosystem will be evaluated through water and nutrient budgets. Subsequent fine-tuning of the operational parameters should allow the project to reach peak performance in two to three years thereafter.

Since the ENR project is both a treatment and demonstration project, there is the need for good accounting of hydrologic, biological, and chemical parameters to monitor and improve performance of the system. A ten gage rainfall network is designed as an initial dense network to sample spatially variable hourly and daily rainfall. Evapotranspiration of the treatment macrophytes and algal covered open water has not been measured in the region. A lysimeter system is designed to solve this problem. Also, with flat topography and low hydraulic heads, flow velocity measurements are not easy. UVMs will be used to measure low velocity flows and its performance will be intensively tested for use in other projects in south Florida. Data gathered in the first year of monitoring will be analyzed and the hydrologic network will be revaluated and changes made accordingly.

Sufficient data will be collected during the first three years of the project to calibrate and validate a two-dimensional mathematical water quantity/quality model. The model will evaluate the effect of various combinations of HLRs, water depths, vegetation types and densities on nutrient removal. The operating schedule of the project will be based on optimization of the long term nutrient removal via peat accretion under the operating conditions developed for the South Florida environment (Koch and Reddy, 1992). The experience, research results, monitoring data, and validated model obtained from this prototype, demonstration-scale project will be used to optimize wetland design and hydrologic management of the full size STAs.

### REFERENCES

- Abtew, W. and N. Khanal. 1993. Water Budget Analysis for the Everglades Agricultural Area: An Organic Soil Drainage Basin. DOR paper #119. South Florida Water Management District. West Palm Beach, Florida.
- Abtew, W., S. Newman, K. Pietro and T. Kosier. 1993. Canopy Resistance Studies of Cattails from Concurrent Observations of Stomatal Conductance and Evapotranspiration. DOR Paper # 131. South Florida Water Management District. West Palm Beach, FL.
- Davis, J.H. 1943. The Natural Features of Southern Florida. Bulletin No. 25, Florida Geological Survey, Tallahassee, FL.
- Davis, S.M. 1991. Growth, Decomposition, and Nutrient Retention of *Cladium jamaicense* Crantz and *Typha domingensis* Pers. in the Florida Everglades. *Aquat. Bot.*, 40, 203-224.
- Everglades Systems Research Division. 1993. Research Implementation Plan: Optimize Operation of Stormwater Treatment Areas for Nutrient Removal. Department of Research. South Florida Water Management District. West Palm Beach, FL. Draft July, 1993.
- Guardo, M. and T. Kosier. 1993. Preliminary Operation Scheme for the ENR Project. Everglades System Research Division. South Florida Water Management District. West Palm Beach, FL.
- Guardo, M. and R. S. Tomasello. 1993. Hydrodynamic Simulations of a Constructed Wetland. Draft Paper. South Florida Water Management District. West Palm Beach, FL.

- Jammal and Associates, Inc., 1991. Geotechnical Services SFWMD Everglades Nutrient Removal Project. Draft report submitted to the South Florida Water Management District. West Palm Beach, FL.
- Koch, M.S., and K. R. Reddy. 1992. Distribution of Soil and Plant Nutrients along a Trophic Gradient in the Florida Everglades. *Soil Sci. Soc. Am. J.*, 56,1492-1499.
- Mitsch, W. J. and J. G. Gosselink. 1986. *Wetlands*. Van Nostrand Reinhold, New York, New York.
- Newman, S., J. Roy, M. Guardo, and J. Obeysekera. 1993. The Florida Everglades Nutrient Removal Project. *International Association on Water Quality. Newsletter No. 9. September, 1993.*
- Roig, L.C. and I.P. King. 1992. Continuum Model for Flows in Emergent Marsh Vegetation. *Proceedings of the 2nd International Conference on Estuarine and Coastal Modeling. ASCE. Tampa, FL. November 13-15, 1992.*
- Swift, D.R., and R. B. Nicholas. 1987. *Periphyton and Water Quality Relationships in the Everglades Water Conservation Areas. Tech. Pub. # 87-2. South Florida Water Management District, West Palm Beach, FL.*

### LIST OF FIGURES

- Figure 1. Location of the Everglades Nutrient Removal Project
- Figure 2. The Everglades Nutrient Removal Project
- Figure 3. Raingages, Lysimeters and Weather Station Location
- Figure 4. Illustration of Lysimeter at the Everglades Nutrient Removal Site
- Figure 5. Flow Vectors Obtained from SHEET-2D Simulations at Day 27 for a  $12.74 \text{ m}^3 \text{ s}^{-1}$  (450 cfs) Inflow

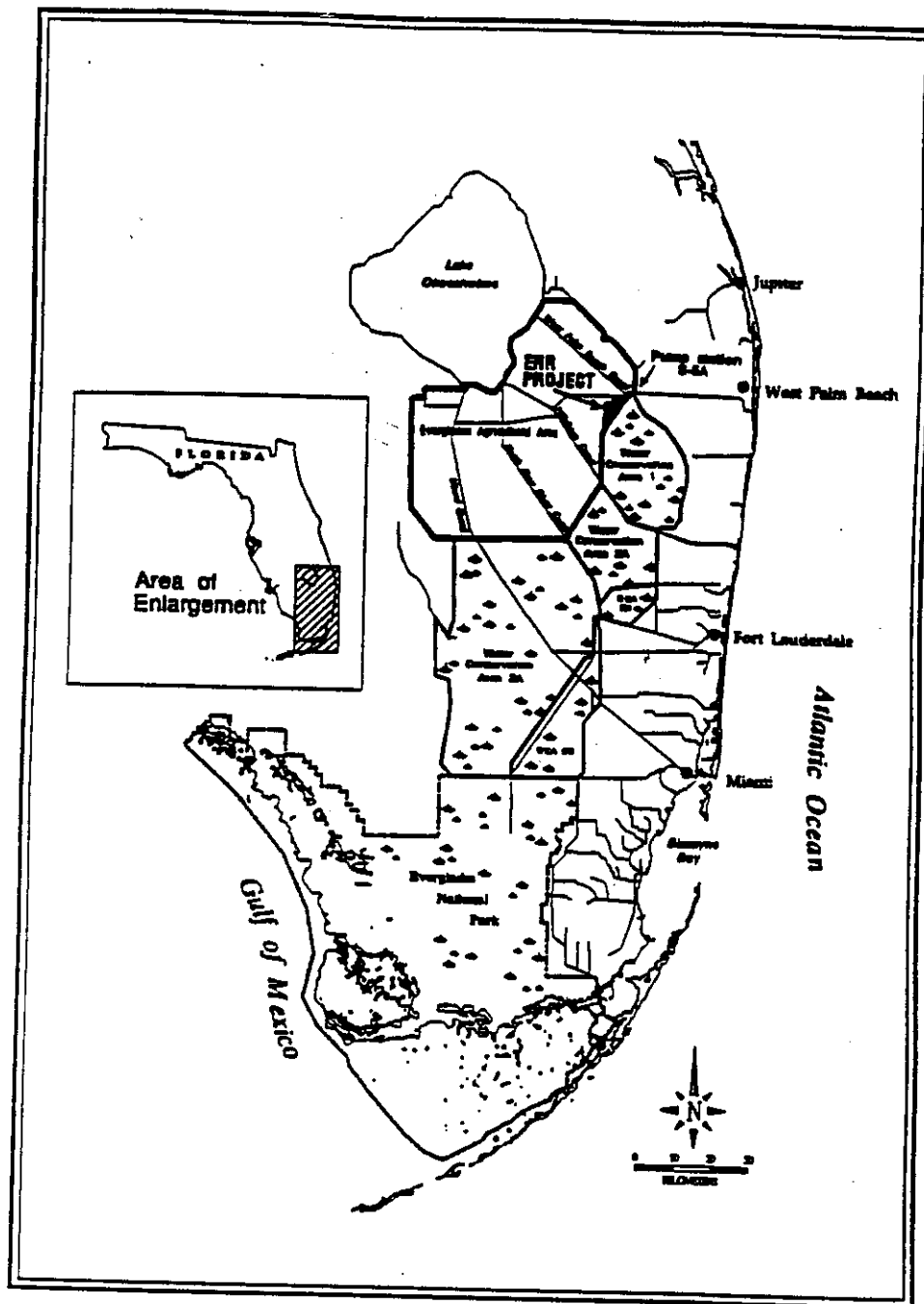


Figure 1. Location of the Everglades Nutrient Removal Project

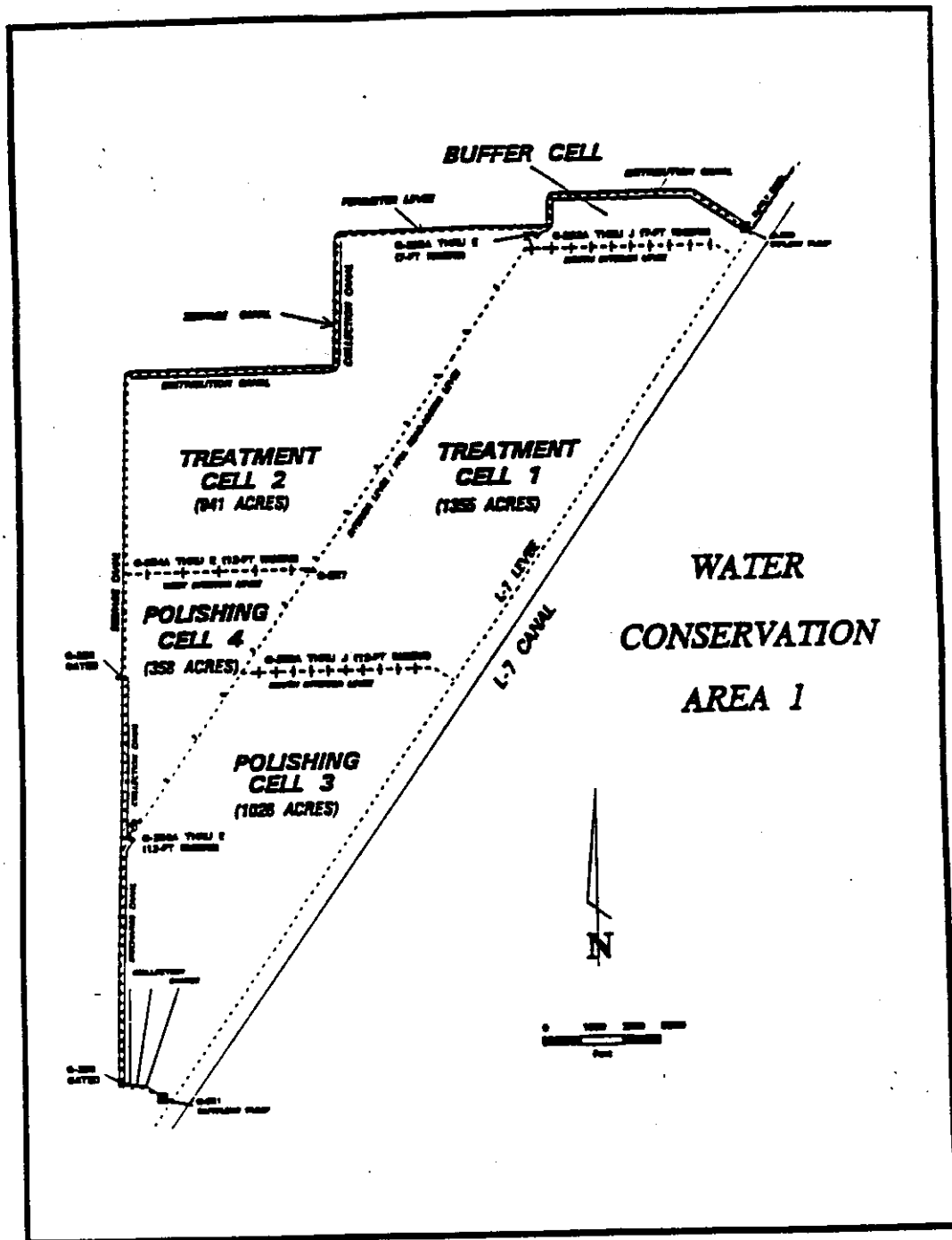


Figure 2. The Everglades Nutrient Removal Project

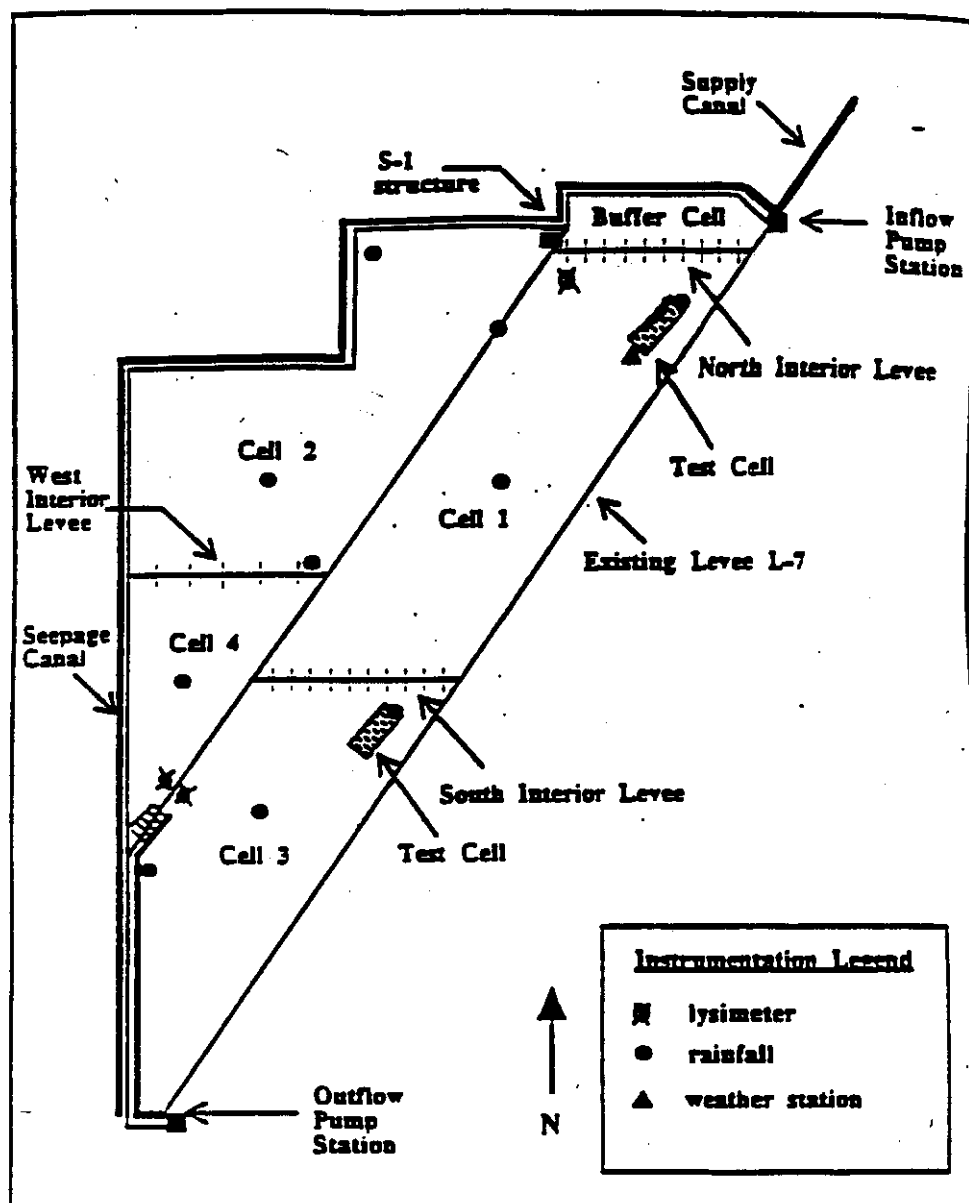


Figure 3. Raingages, Lysimeters and Weather Station Location



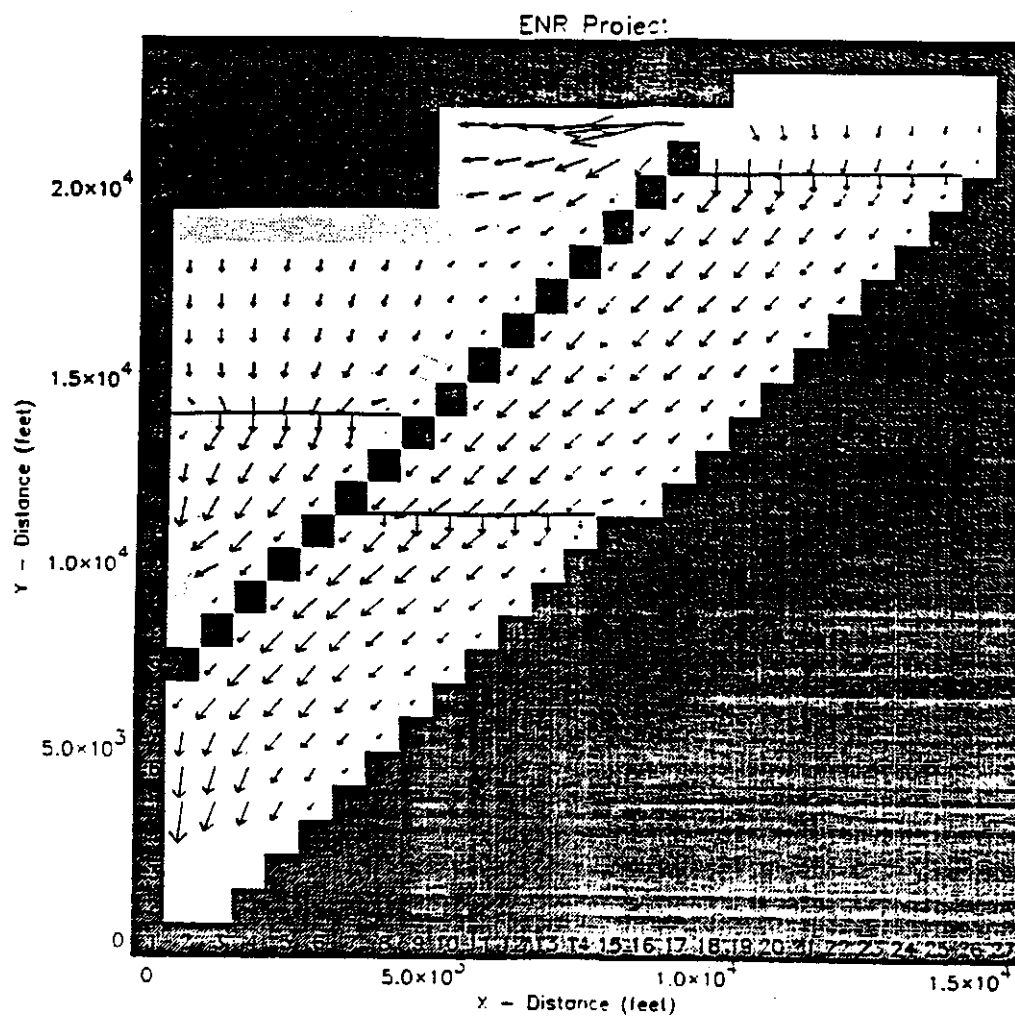


Figure 5. Flow Vectors Obtained from SHEET-2D Simulations at Day 27 for a  $12.74 \text{ m}^3 \text{ s}^{-1}$  (450 cfs) Inflow